

Appendix H

Details of Regional Ground-level Ozone Interpolation

Methods

The study area of Shenandoah National Park in Virginia was expanded to six eastern states (VA, MD, PA, WV, NC, and OH) in order to interpolate ozone exposures in the area of interest. By interpolating over a larger region we believe our estimate of ozone exposure in the Park is more robust. The expanded study area was represented by a 15-arc-second digital elevation model (DEM) and projected to an Albers equal-area conic map projection. Elevation data are from the United States Geological Survey (USGS) Conterminous U.S. Advanced Very High Resolution Radiometer Companion Disc (Loveland et al. 1991) and re-sampled by the USGS to 1 km resolution. Elevation data from the DEM on a 4 km grid were used to spatially interpolate monthly air temperature at high spatial resolution and, subsequently with air temperature, to interpolate ozone exposure at the same resolution.

The loess regression/kriging statistical interpolation approach presented in Lee and Hogsett (2001) was used to generate high-resolution maps of monthly SUM06 values using monitoring data for ozone in conjunction with elevation and temperature data sampled at higher spatial density. The inclusion of elevation and temperature significantly improved the ability to predict ozone exposures over complex terrain and overcomes the data limitations imposed by poor spatial coverage of the ozone-monitoring network. The elevation-based interpolation method produced accurate and precise temperature and ozone exposure surfaces that had desirable statistical properties and were logically consistent with topographical features and atmospheric conditions known to influence ozone formation and transport.

Ambient ozone exposure was characterized using the 5-month 12-h SUM06 index for assessing the ecological risk of ozone to tree species in Shenandoah National Park. Monthly SUM06 values were calculated as the sum of all hourly ozone concentrations ≥ 0.06 ppm between 0800 and 2000 for May to September 1997-1999. Prediction surfaces for the monthly SUM06 values were generated using the loess/kriging interpolation method and summed to calculate the prediction surface for the 5-month SUM06 index.

Hourly ozone monitoring data were obtained from the EPA's Aerometric Information Retrieval System (AIRS). About 150 AIRS monitoring stations denoted as either rural or suburban and reporting a land use of forest, agricultural, residential, desert or mobile received highest priority in the analysis. Urban, city-center monitoring sites in close proximity to a "non-urban" site were excluded from the analysis to minimize the effect of nitric oxide scavenging in urban areas (Logan 1989). The majority of monitoring sites in the AIRS database were located nearby major urban centers and at lower elevation. Consequently, background ozone concentrations at the suburban and rural sites are likely influenced by pollutant plume transport from downwind urban sources to varying degrees.

Monthly 12-h SUM06 values were calculated as the sum of hourly ozone concentrations ≥ 0.06 ppm between 0800 and 2000 and were adjusted for missing values by a multiplicative factor equal to the number of days in the month times 12 divided by the number of available hourly ozone concentrations. Daily SUM06 values were considered valid if at least nine hourly ozone concentrations between 8:00 AM and 8:00 PM were available for calculation. The adjusted monthly SUM06 values were retained for analysis if there were at least 75 percent valid days in the month. Initially, the number of ozone monitoring stations that met our data completeness criterion ranged from 140 for May 1997 to 158 for July 1999. There were large gaps in spatial coverage in non-urban areas and at higher elevations (Figure H-1).

Maximum daily temperature data were obtained from monitoring stations from the National Weather Service (NWS) cooperative network archived at the National Climatic Data Center

(NCDC). Daily temperature data for 1997 and 1998 were available for about 550 meteorological stations from the NCDC Summary of the Day TD-3200 database purchased from EarthInfo (EarthInfo 1992). Daily temperature data for 158 meteorological stations for 1999 were obtained directly from NCDC. The locations of these stations are shown in Figure H-2. The more densely sampled temperature data were used in the first stage of the analysis to predict mean monthly temperature values at the geographic locations of the ozone monitoring stations.

Results

The monthly mean daily maximum temperature was interpolated at the geographic locations for the ozone monitoring stations based on separate loess/kriging models for each month. Loess regression was used to model the large-scale variability in monthly temperature as a function of geographic location, elevation, and coastal proximity. Kriging of the loess residuals was used to model the small-scale spatial dependencies as a function of relative spatial location. All calculations were performed in MathSoft Splus V5.1 and its accompanying module S+Spatialstats V1 (MathSoft, 1996, 1998). The loess fits had R^2 values ranging from 0.78 to 0.89 and residual standard errors (RSEs) ranging from 0.78 C to 0.92 C (Table H-1).

For each region, the weighted nonlinear least squares approach was used to fit a spherical variogram model to the empirical one as a function of relative spatial location (Cressie 1985). A dominant nugget effect was observed for most months and indicated a weak covariance structure among neighboring sampled points (Table H-2). Consequently, kriging gave marginal improvements in accuracy and precision in temperature predictions for the eastern United States.

Loess regression was used to model the large-scale variability in monthly SUM06 values as a function of geographic location, elevation, and predicted monthly mean daily maximum temperature. The loess fits had R^2 values ranging from 0.17 to 0.78 and residual standard errors (RSEs) ranging from 1.37 to 3.23 ppm-h (Table H-3). The low R^2 value for May 1998 was attributed to low spatial variability in monthly SUM06 values and did not indicate poor predictive ability. The loess predictions for monthly SUM06 values were as precise for May 1998 as other months in 1998 based on the RSE.

Except for September 1997 and 1999, the range parameter in the spherical variogram model was less than 70 km indicating that sampled points within a 70 km radius largely influence the kriged prediction of the SUM06 residual at an unsampled point. Consequently, kriging gave marginal improvements in accuracy and precision in SUM06 predictions for the Shenandoah National Park area because of the sparse spatial coverage of the ozone-monitoring network (Table H-4).

Figures H-3 to H-5 show the spatial extrapolation of ozone over the region for 1997-1999.

Table H-1. Locally quadratic loess fits for monthly mean daily maximum air temperature as a function of elevation, geographic location and coastal proximity.

	1997 ¹				1998				1999 ²			
Month	# Obs.	Residual SE (C)	R^2	Span	# Obs.	Residual SE (C)	R^2	Span	# Obs.	Residual SE (C)	R^2	Span
May	685	0.83	0.92	0.65	521	0.85	0.80	0.50	556	0.81	0.79	0.60
June	686	0.81	0.80	0.50	524	0.89	0.89	0.60	559	0.83	0.78	0.50
July	685	0.88	0.84	1.00	523	0.87	0.86	0.60	558	0.84	0.81	0.60
August	685	0.84	0.89	1.00	527	0.82	0.83	0.50	561	0.83	0.88	0.60
Sept	685	0.82	0.89	0.80	538	0.86	0.86	0.40	563	0.78	0.81	0.70

¹ Meteorological stations for TN and KY were included in 1997 but were excluded in 1998 and 1999.

² Maximum daily temperature data for 1999 were obtained from NCDC by Chris Daly.

Table H-2. Kriging models for loess residuals for monthly mean daily maximum air temperature as a function of spatial distance.

Month	1997			1998			1999		
	Range (km)	Sill (°C ²)	Nugget (°C ²)	Range (km)	Sill (°C ²)	Nugget (°C ²)	Range (km)	Sill (°C ²)	Nugget (°C ²)
May	NA	NA	NA	72	0.32	0.34	112	0.14	0.47
June	161	0.14	0.48	72	0.29	0.41	82	0.24	0.42
July	112	0.17	0.52	109	0.24	0.47	93	0.17	0.52
August	169	0.20	0.46	89	0.20	0.47	68	0.26	0.37
Sept	114	0.19	0.44	107	0.19	0.52	118	0.17	0.42

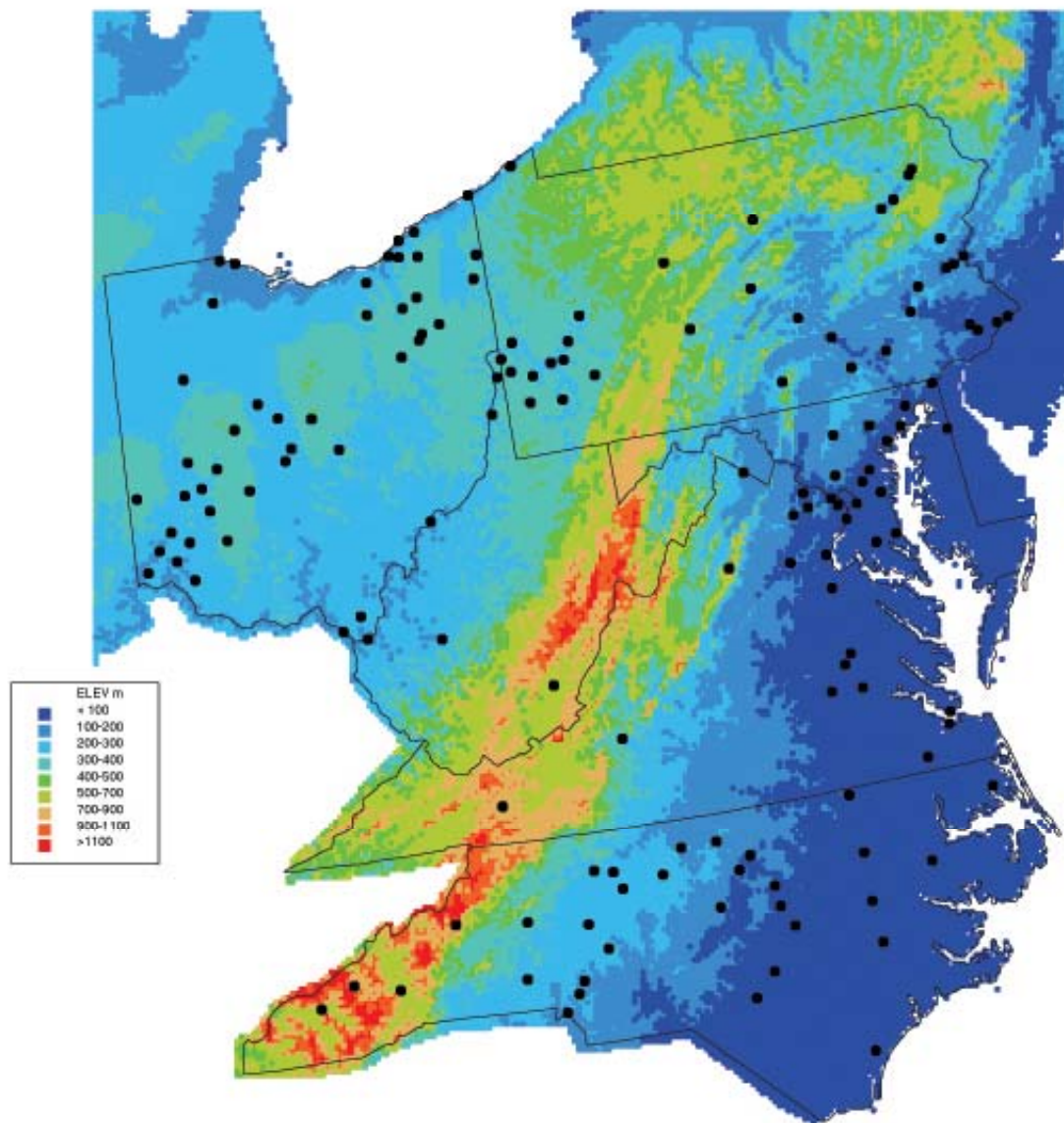
Table H-3. Locally quadratic loess fits for monthly 12-h SUM06 ozone exposure index as a function of elevation, geographic location and monthly mean daily maximum temperature.

Month	1997 ¹				1998				1999 ²			
	# Obs.	Residual SE (ppm-h)	R ²	Span	# Obs.	Residual SE (ppm-h)	R ²	Span	# Obs.	Residual SE (ppm-h)	R ²	Span
May	140	1.45	0.77	2.50	150	2.01	0.17 ¹	1.80	156	2.58	0.32	2.00
June	142	2.08	0.51	1.80	151	1.91	0.63	1.80	157	2.14	0.50	1.80
July	142	2.71	0.55	2.50	151	2.48	0.59	1.00	158	3.23	0.44	2.00
August	143	1.93	0.67	1.40	151	2.30	0.53	1.00	158	2.49	0.78	2.00
Sept	143	1.37	0.70	1.00	150	1.97	0.66	0.60	155	1.44	0.69	2.00

¹ Low r² in May 1998 was due to low spatial variability in monthly SUM06 values which had an interquartile range equal to 2.4 ppm-h. Note that the RSE was 2.01 ppm-h for May 1998 so that the loess regression had as much precision in spatial predictions as other months.

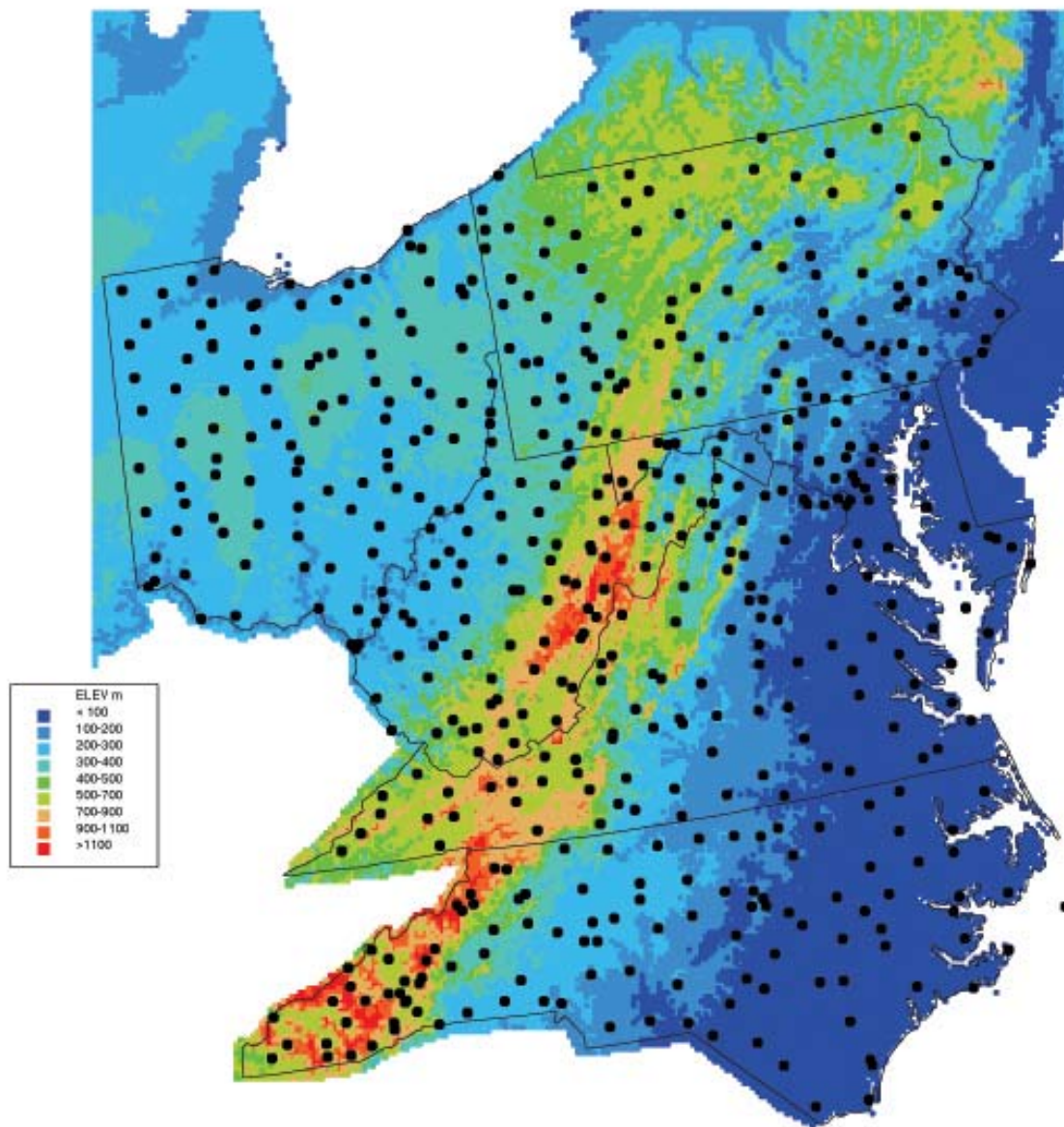
Table H-4. Kriging models for loess residuals for monthly 12-h SUM06 ozone exposure index as a function of spatial distance.

Month	1997			1998			1999		
	Range (km)	Sill (ppm-h) ²	Nugget (ppm-h) ²	Range (km)	Sill (ppm-h) ²	Nugget (ppm-h) ²	Range (km)	Sill (ppm-h) ²	Nugget (ppm-h) ²
May	NA	NA	NA	NA	NA	NA	46	3.59	1.26
June	NA	NA	NA	30	2.80	0.41	48	3.05	0.87
July	48	4.38	1.55	38	5.21	0.29	69	5.32	3.08
August	41	2.71	0.12	48	2.62	2.06	48	2.62	2.06
Sept	113	0.61	0.71	NA	NA	NA	203	0.47	1.20



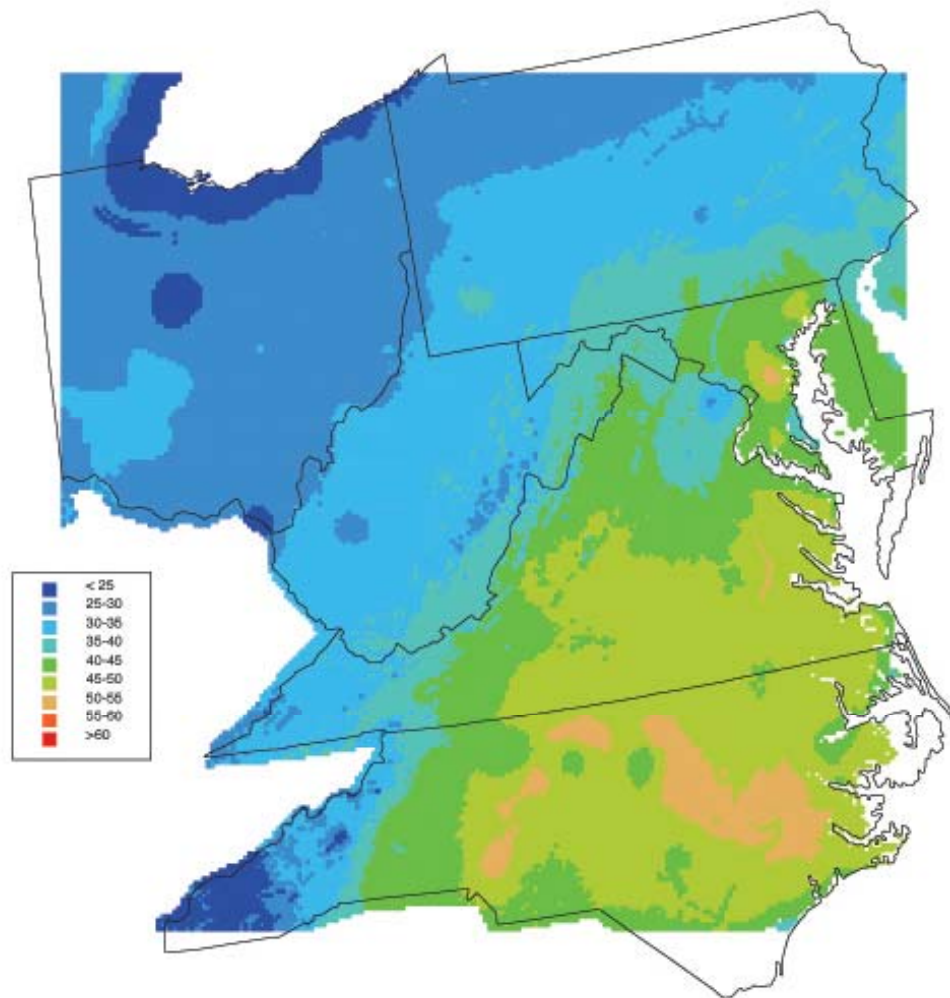
U.S. EPA's AIRS monitoring stations for 1998.

Figure H-1. EPA AIRS ozone monitoring stations for 1998.



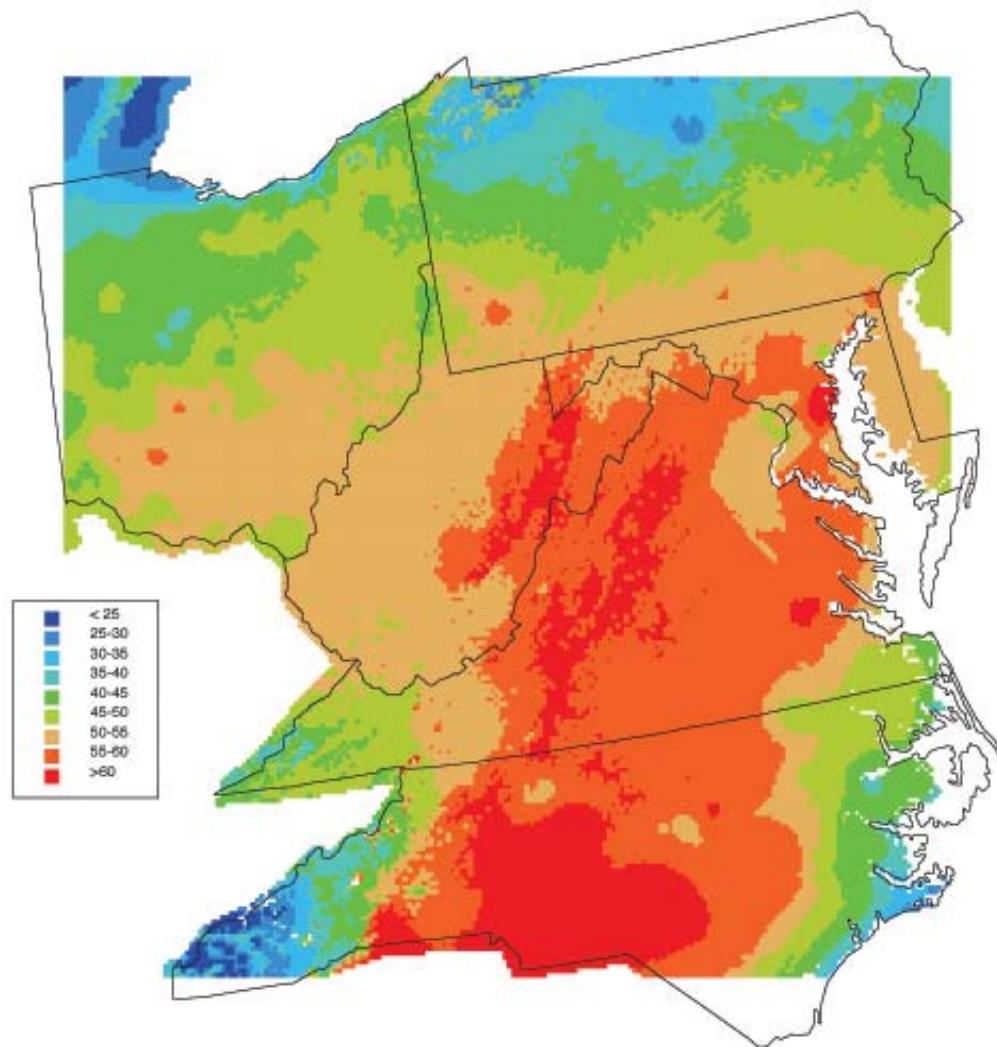
Earthinfo meteorological monitoring stations for 1998.

Figure H-2. NCDC meteorological stations in 1998.



Spatial interpolation of 5-month 12-h SUM06 for 1997 on 4-km grid.

Figure H-3. Spatial extrapolation of the 5 month 12 hour SUM06 for 1997 on a 4 km grid.



Spatial interpolation of 5-month 12-h SUM06 for 1998 on 4-km grid.

Figure H-4. Spatial extrapolation of the 5 month 12 hour SUM06 for 1998 on a 4 km grid.

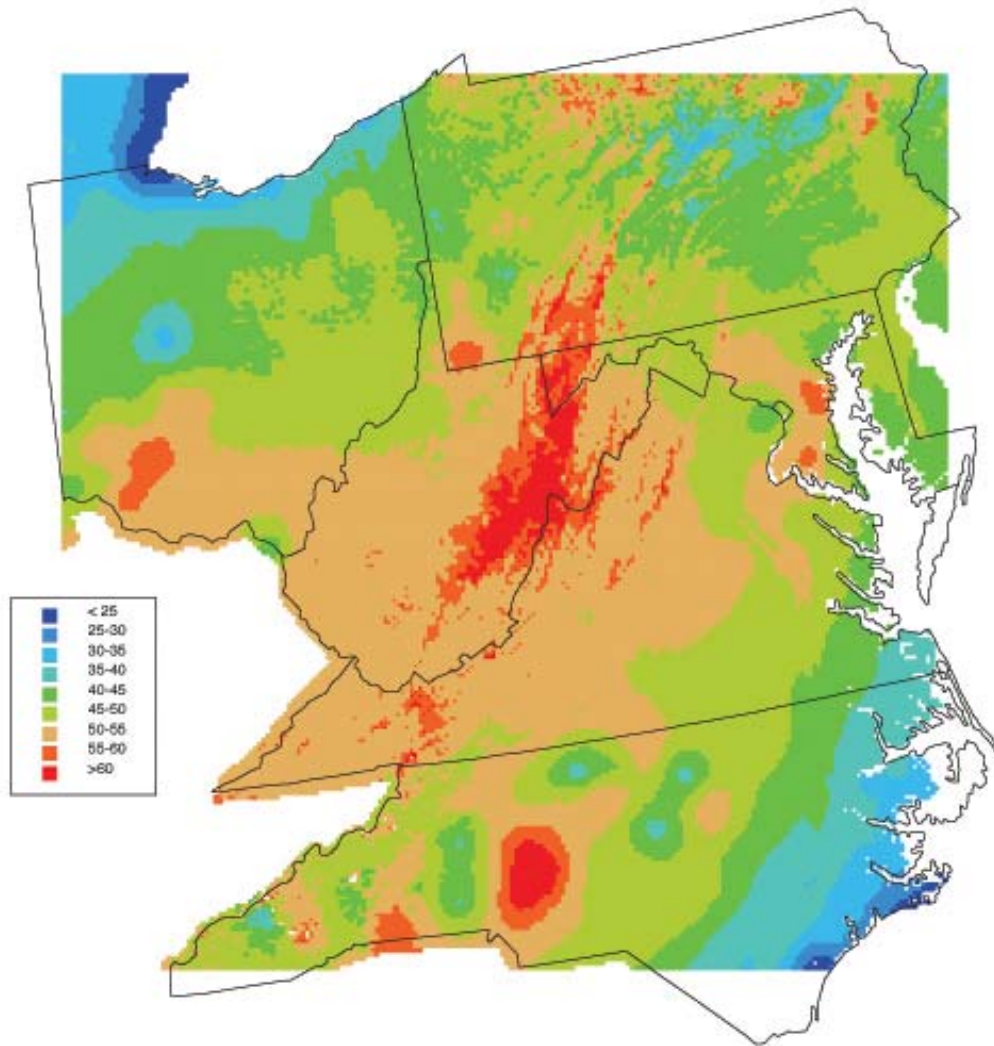


Figure H-5. Spatial extrapolation of the 5 month 12 hour SUM06 for 1999 on a 4 km grid.

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